International Journal of Mechanical and Production Engineering Research and Development (IJMPERD)
ISSN (P): 2249–6890; ISSN (E): 2249–8001
Vol. 9, Issue 5, Oct 2019, 1057–1064

STUDY OF RAW MATERIALS WITH THE AIM OF OBTAINING CERAMIC FILLER AND HEAT-INSULATING AND STRUCTURAL WALL CERAMICS

SARSENBEK ALIAKBARULY MONTAEV, NURGUL BOLATOVNA ADILOVA, NURGUL SARSENBEKOVNA MONTAEVA, KARZHAUBAI ZHANABAYEVICH DOSOV & AINUR AMANGALIEVNA TAUDAEVA

West Kazakhstan Agrarian-Technical University, Uralsk, Kazakhstan

ABSTRACT

The article presents the results of a comprehensive study of the chemical and mineralogical composition and the physical and mechanical properties of raw materials in the form of granulated blast furnace slag used at the Karaganda metallurgical plant of JSC ArselorMittal Temirtau, raw clay, silica rock – gaize and bentonite clay from the Pogodaevsk field in Western Kazakhstan. The composition of two kinds of raw materials was studied: 1. Loam 70–90%; blast-furnace granulated slag 10–30% and 2. Gaize 75–97%; Bentonite slurry 3–25%. The first composition is intended for obtaining ceramic filler, the second composition for obtaining heat-insulating structural wall ceramics. Based on the studied compositions, pellet samples were prepared along with ceramic cubes. The obtained samples were annealed in an electric furnace at 1,000–1,100°C and 950–1,000°C, respectively. The heat-treated samples were subjected to physical and mechanical tests for determining the average density, compressive strength, water absorption, and thermal conductivity. Pellet samples had the compressive strength of 9.2–13.4 MPa, and the samples of insulating ceramics – 9.6–14.2 MPa. The heat conductivity for the filler was 0.1–0.24 W/(m °C), for the wall ceramics - 0.2 to 0.52 W/(m °C). Thus, the possibility of obtaining the efficient and highly needed materials in the form of ceramic filler and insulating structural wall ceramics based on the developed composites has been found.

***KEYWORDS:** Clay, Gaize, Ceramics, Ceramic Filler & Heat Conductivity*

Received: Jun 25, 2019; **Accepted**: Jul 15, 2019; **Published**: Sep 27, 2019; **Paper Id.**: IJMPERDOCT201994

Original Article

INTRODUCTION

The growing volume of construction of housing and industrial, road, and agricultural facilities in Kazakhstan consumes huge amounts of materials, products, and structures manufactured from raw materials of the mineral origin. At the same time, technogeneous mineral wastes in the Republic of Kazakhstan today amount to almost 20 billion tons, which deteriorate the environment and occupy large areas of the dump sites, although they could be a cheap raw material for manufacturing building materials that are not readily available. The successful use of technogeneous mineral wastes requires developing scientifically substantiated innovative solutions for creating resource-saving technologies for obtaining high-quality materials.

With that, the most demanded materials in the modern roads construction are coarse aggregate in the form of crushed stone and artificial aggregates, and in civil engineering - wall ceramics.

In Kazakhstan, dump sites with the accumulated millions of tons of unused blast furnace slag at JSC ArselorMittal Temirtau approach the maximum permissible amount and are consumed in very small amounts for the needs of the enterprise.

The research performed by the authors, Netinger et al. (2016), Aghaeipour and Madhkhan (2017), Nguyen et al., (2018), Higashiyama et al., (2014), Ulubeyli and Artir (2015) proves the suitability of this industrial byproduct in a wide range of civil construction areas as an additive to the cement and in concrete structures.

In an experimental study by Abdollahnejad et al., (2018), a combination of ceramic wastes and granulated blast furnace slag was used for preparing single-component alkali-activated binders.

In works, Ozturka and Gultekin (2015), Ozdemir and Yilmaz (2007), Ghosh et al., (2002), Favoni et al., (2005), Lu et al., (2019), blast furnace slag was considered as a potential source of secondary raw material for the production of ceramic products.

Research works in the field of creating new composite materials are in progress with the aim of improving the quality of road pavements.

The authors Silvestre et al., (2013) studied the technical feasibility of using recycled ceramic aggregates for partial replacement of natural aggregates in the asphalt hot mix.

The possibility of using the steel slag as a coarse aggregate in the lower structure of roads has been experimentally proven (Kandhal, Hoffman, 1997; Collins, Ciesielski, 2007; Wu et al., 2007; Behiry, 2013).

Modern resource and energy-saving requirements point to the need for switching brick production to manufacture efficient porous wall materials.

The problems in the production of efficient heat-insulating wall materials are determined by the insufficient raw material resources base.

Works, Govorova et al., (2015), Darweesh (2001), Yanık et al., (2010) are devoted to study the possibility of improving the strength and characteristics of ceramic brick made of low melting clays with the use of natural raw material additives.

In the West of Kazakhstan, there is one of the largest deposits of siliceous rock, gaize, which can be used as the main raw materials resource in the production of wall ceramics.

The authors, Kotlyar et al., (2017) have developed a technology for obtaining high-performance ceramic products with the average density not less than 700–800 kg/m^3 and the conductivity less than 0.15–0.20 W/(m °C) at the minimum cost.

Thus, developing innovative technologies for obtaining composite materials with various functionality and improved characteristics is an important task of modern materials science.

The purpose of the research is studying raw materials and developing new formulations of ceramic fillers and heat insulating structural wall ceramics.

MATERIALS AND METHODS

With the aim of obtaining an efficient composition for producing ceramic filler, the clay from the Chaganskoe field in Western Kazakhstan and wastes of blast furnace slag from JSC "ArcelorMittal Temirtau" were studied as the main raw material components. Samples of clay raw materials were taken, and the methods for studying their properties were chosen in accordance with GOST 5180 and GOST 12248, GOST 12536, GOST 22733, GOST 23161, GOST 23740, GOST 24143, GOST 26263, GOST 30416, and GOST 21216.

Table 1: Elemental Composition of Clay

Element	C	O	Na	Mg	Al	Si	K	Ca	Ti	Mn	Fe
Weight, %	7.99	50.94	0.64	1.41	5.47	19.40	1.66	7.58	0.28	0.08	4.54
Atomic, %	12.92	61.83	0.54	1.13	3.94	13.42	0.82	3.67	0.11	0.03	1.58

For studying the properties of granulated blast furnace slag, GOST 3476 was used.

The microstructure of the ceramic compositions was studied on raster electronic microscope JSM-6390LV and on device JEM-6610LA (made by JEOL, Japan).

The elemental compositions were analytically studied on X-ray diffractometer X´Pert PRO (Japan).

The loess loam from the Chaganskoe field (West Kazakhstan region) was used as the loamy component. figure 1 shows the results of studying the clay from the Western Kazakhstan field by the method of scanning electron microscopy (SEM). Table 1 shows the elemental composition of clay.

The granulated blast furnace slag from the Karaganda metallurgical plant of JSC ArcelorMittal Temirtau (Temirtau) was used as the modifying additive. It is a granular gray material. Fineness modulus is 3.9–4.1.

Rapid cooling of the molten slag during the granulation process mainly determines its vitreous structure. The content of the glass phase is 65–97%. The crystallized part of the slag is mainly represented by pseudowollastonite α–$CaO*SiO_2$ with a refractive index (table 2)

$Ng = 1.652 \pm 0.0015$; $Np = 1.608 \pm 0.0015$.

In the natural state, the slag is X-ray-amorphous.

Studying the macrostructure of granulated blast furnace slag (figure 2) has shown that the slag particles in their natural state are threaded with micro and macropores.

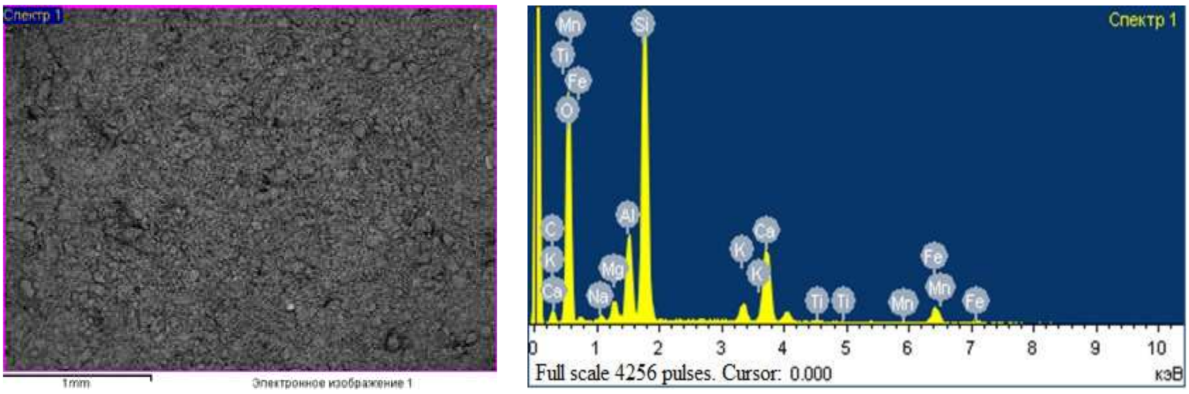

Figure 1: The Results of Studying the Clay from the West Kazakhstan Field using the Method of Scanning Electron Microscopy (SEM)

Table 2: Chemical Composition of Granulated Blast Furnace Slag

Name of Raw Material	**Oxides Content, wt.%**												
	SiO_2	**Al_2O_3**	**Fe_2O_3**	**CaO**	**FeO**	**MgO**	**SO_3**	**Na_2O**	**K_2O**	**CO_2**	**TiO_2**	**S_hO**	**LOI**
Granulated blast-furnace slag from the Karaganda metallurgical plant	40.62	16.24	0.19–0.52	42.11	0.43	5.33–10.39	1.66	0.36–1.5	0.42–1.32	-	0.62–0.88	0.11–1.37	0.92

Figure 2: The Macrostructure of Granulated Blast Furnace Slag from the Karaganda Metallurgical Plant.

The results of X-ray phase analysis of the samples containing various amounts of granulated blast furnace slag and annealed at 800, 900 and 1,000 °C showed that at 800°C the main crystalline phases in all samples were melilite, anortite and β-cristobalite (Montayev, Suleymenov, 2006). With the increase in the temperature of annealing, the amount of all crystalline phases increases, as evidenced by increased intensity of the diffraction peaks. In addition, diffraction peaks of minor intensity were observed, which were characteristic by wollastonite.

Siliceous rock (gaize) and bentonite clay from Western Kazakhstan were studied as the raw materials components in the composition for manufacturing heat insulating structural ceramic bricks.

During the study, it has been found that clay-containing gaizes (from the Taskala field) of light gray and dark yellow color are fairly strong, and, when wetted, acquire the grayish-greenish hue. The structure is usually massive. Along small, barely emerging cracks, the concentration of iron hydroxides is often observed.

The results of the analysis show that the main opaline mass of the rock is literally "saturated" with the clay-like substance. This makes it difficult to determine the refractive index of the main mass. At high magnification, the mostly needle-like and table-like structure of the main mass of clay minerals is observed. The clay component is present in the amount of 20–50%. Occasional organogenous residues in the form of sponge spicules are observed. The siltstone material is represented mainly by unrounded quartz grains (up to 15%) and glauconite grains (about 5%) of bright-green color. Relatively large (upto 0.5 mm) flakes of mica are observed quite often. Along the microcracks, the concentration of iron hydroxides is clearly visible. The elemental composition is shown in table 3 and figure 3.

The clay from the Pogodaevsk field, by its refractory properties, belongs to fusible clays, by the content of Fe2O3 –to clays with a high content of coloring oxides, and by the content of Al2O3 – to the group of sour raw materials (table 4).

Table 3: Elemental Composition of Gaize

Element	O	Na	Mg	Al	Si	S	K	Ca	Ti	Fe
Weight, %	53.68	0.21	0.55	3.40	36.53	0.19	1.18	1.33	0.18	2.75
Atomic, %	67.97	0.18	0.46	2.55	26.35	0.12	0.61	0.67	0.08	1.00

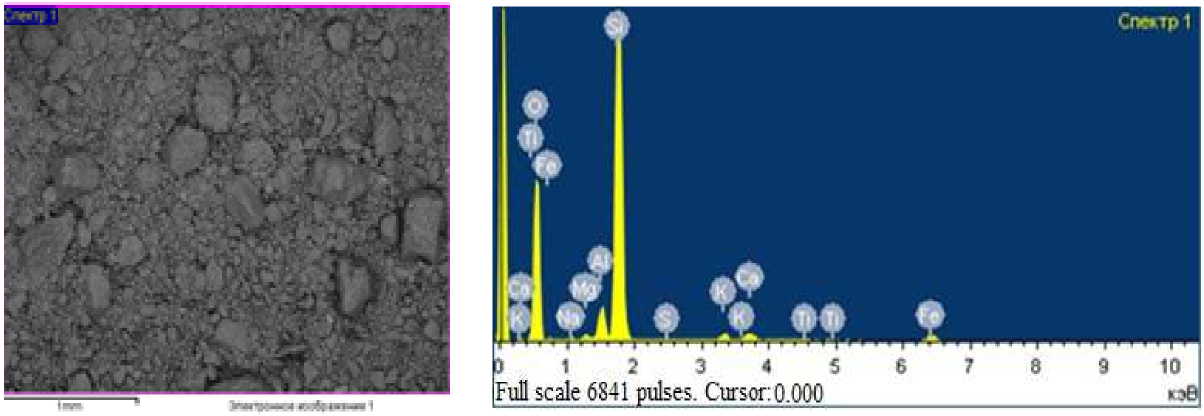

Figure 3: The Result of Analyzing the Scanning Electron Microscopy for Gaize.

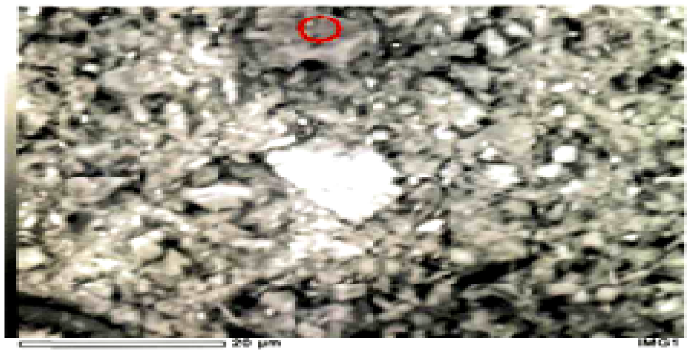

Figure 4: The Microstructure of the Bentonite Clay from the Pogodaevsk Field.

Table 4. The Chemical Composition of the Bentonite Clay from the Pogodaevsk Field in West Kazakhstan Compression Strength, MPa

Name of Raw Materials	Oxides Content, wt.%							
	SiO_2	Al_2O_3	CaO	MgO	Fe_2O_3	SO_3	Na_2O	LOI.
Pogodaevsk Field	61.51	17.06	2.27	3.21	6.36	1.27	3.57	6.75

The mineralogical composition of the clay (figure 4) is mainly represented by montmorillonite d/n = 5.06; 4.46; 3.79; 3.06; 2.455; 2.28; 2.127; 1.977; 1.817; $1.675*10^{-10}$m.

RESULTS

The area of studying the component compositions of the ceramic filler consists of the following maximum concentrations of components, wt.%:

The clay from the West Kazakhstan field - 70–90;

Blast-furnace granulated slag - 10–30.

Joint mixing was performed in a two-shaft mixer with the addition of water, followed by forming granules with dimensions of 5–10 mm, 10–20 mm, and 20–40 mm. The granules were dried in a drying cabinet at the temperature of 70–80°C.

The composite structure of the insulating structural wall material was studied in the raw materials system Gaize–Bentonite slurry.

Table 5: Physicomechanical Properties of Samples of the Ceramic Filler and Insulating Structural Ceramics

Material name	Component Compositions, %	Temperature of Annealing, °C	Average Density, kg/m^3	Compressive Strength, MPa	Water Absorption ability, %	Heat Conductivity, W/mK
Ceramic Filler	Loam 70–90 Slag 10–30	1,000–1,100	920–1,200	9.2–13.4	14.1–14.8	0.1–0.24
Insulating Structural Ceramics	Gaize 75–97 Bentonite slurry 3–25	950–1,000	850–1,250	9.6–14.2	22.5–28.1	0.2–0.5

The silica rock-gaize was subjected to grind the specific surface area of 1,200–1,500 cm^2/g. From the bentonite clay, a suspension with the density of 1.3–1.4 g/cm^3 was prepared. The raw material mixture was molded by dry pressing at the pressure of 15–20 MPa. The molded products were annealed without pre-drying. The following maximum contents of components (in wt.%) were chosen for the study:

Silica rock – Gaize - 70–95%;

Bentonite slurry - 3–30%.

For the study, the following most important performance characteristics of the ceramic formed by heat treatment were chosen: compressive strength, average density, water absorption ability, and thermal conductivity (table 5).

CONCLUSIONS

- The methods of using blast furnace slag in the production of construction materials have been studied. It has been found that blast furnace granulated slag is widely used in civil engineering. However, it is used as a full-scale additive for reinforcing the structure of loamy raw materials and obtaining high-quality ceramic filler has been insufficiently studied.
- The raw materials have been comprehensively studied with the aim of determining the chemical and mineralogical composition and the physical and mechanical properties.
- The possibility of obtaining the efficient and highly needed materials in the form of ceramic filler and insulating structural wall ceramics based on the developed composites has been found.
- The formation of structure-reinforcing minerals in the clay-slag ceramic compositions that improve their physicomechanical properties has been noted.
- The positive effect of adding bentonite slurry into the ceramic mass has been studied and proven. It improves the mechanical and heat-conducting properties of heat-insulating structural wall material.
- Practical implementation of the research results will promote the recycling of granulated blast furnace slag up to 30% and expanding the raw material resources base in the ceramic industry.

REFERENCES

1. *Abdollahnejad, Z., Mastali, M., Luukkonen, T., Kinnunen, P., Illikainen, M. (2018). Fiber-reinforced one-part alkali-activated slag/ceramic binders. Ceramics International, 44(8), 8963–8976.*
2. *Aghaeipour, A., Madhkhan, M. (2017). Effect of ground granulated blast furnace slag (GGBFS) on RCCP durability. Construction and Building Materials, 141, 533–541.*

3. Behiry, A.E.A.E.M. (2013). Evaluation of steel slag and crushed limestone mixtures as subbase material in flexible pavement. Ain Shams Engineering Journal, 4(1), 43–53.
4. Collins, R.J., Ciesielski, S.K. (2007). Recycling and use of waste materials and by-products in highway construction. National cooperative highway research program, synthesis of highway practice 199, TRB, Washington, DC.
5. Darweesh, H.H.M. (2001). Building materials from siliceous clay and low grade dolomite rocks. Ceramics International, 27(1), 45–50.
6. Favoni, C., Minichelli, D., Tubaro, F., Brückner, S., Maschio, S. (2005). Ceramic processing of municipal sewage sludge (MSS) and steelworks slags (SS). Ceramics International, 31(5), 697–702.
7. Ghosh, S., Das, M., Chakrabarti, S., Ghatak, S. (2002). Development of ceramic tiles from common clay and blast furnace slag. Ceramics International, 28(4), 393–400.
8. Govorova, L.P., Vakalova, T.V., Shvagrukova, E.V., Zagaynova, L.A. (2015). Influence of Stony Rocks Additives on Strengthening of Aluminosilicate Ceramics from Fusible Clays. Procedia Chemistry, 15, 120–126.
9. Higashiyama, H., Sappakittipakorn, M., Mizukoshic, M., Takahashid, O. (2014). Efficiency of ground granulated blast-furnace slag replacement in ceramic waste aggregate mortar. Cement and Concrete Composites, 49, 43–49.
10. Kandhal, P.S., Hoffman, G.L. (1997). Evaluation of steel slag fine aggregate in hot-mix asphalt mixtures. Transp Res Rec, 1583, 28–36.
11. Kotlyar, V.D., Lapunova, K.A., Kozlov, G.A. (2017). Wall Ceramics Products based on Opoka and Coal Slurry. Procedia Engineering, 150, 1452–1460.
12. Lu, G., Liu, P., Wang, Y., Faßbender, S., Oeser, M. (2019). Development of a sustainable pervious pavement material using recycled ceramic aggregate and bio-based polyurethane binder. Journal of Cleaner Production, 220, 1052–1060.
13. Maddaiah, M., Kumar, A. G. S., Obulapathi, L., Sarmash, T. S., Naidu, K. C. B., Rani, D. J., & Rao, T. S. (2015). Synthesis and characterization of strontium doped zinc manganese titanate ceramics. Digest Journal of Nano materials and Biostructures, 10, 155–159.
14. Montayev, S.A., Suleymenov, Z.T. (2006). Stenovayakeramika na osnovekompozitsiitekhnogennogoiprirodnogosyryaKazakhstana [Wall ceramic based on the compositions of technogeneous and natural raw materials in Kazakhstan]. Monograph. Almaty: Gylym.
15. Netinger, I., Barišić, I., Fucic, A., Bansode, S.S. (2016). Application of blast furnace slag in civil engineering: Worldwide studies. Characteristics and uses of Steel Slag in Building Construction, 51–66.
16. Nguyen, T.H.Y., Tsuchiya, K., Atarashi, D. (2018). Microstructure and composition of fly ash and ground granulated blast furnace slag cement pastes in 42-month cured samples. Construction and Building Materials, 191, 114–124.
17. Ozdemir, I., Yilmaz, S. (2007). Processing of unglazed ceramic tiles from blast furnace slag. Journal of Materials Processing Technology, 183(1), 13–17.
18. Ozturka Z.B., Gultekin, E.E. (2015). Preparation of ceramic wall tiling derived from blast furnace slag. Ceramics International, 41(9), 12020–12026.
19. Silvestre, R., Medel, E., García, A., Navas, J. (2013). Using ceramic wastes from tile industry as a partial substitute of natural aggregates in hot mix asphalt binder courses. Construction and Building Materials, 45, 115–122.

20. *Srikanth, D. V., & Rao, M. S. (2014). Application of optimization methods on abrasive jet machining of ceramics. International Journal of Industrial Engineering & Technology (IJIET), 4(3), 23–32.*

21. *Ulubeyli, G.C., Artir, R. (2015). Sustainability for Blast Furnace Slag: Use of Some Construction Wastes. Procedia - Social and Behavioral Sciences, 195, 2191–2198.*

22. *Wu, S., Xue, Y., Ye, Q. (2007). Utilization of steel slag as aggregates for stone mastic asphalt (SMA) mixtures. Build Environ, 42, 2580–2585.*

23. *Yanık, G., Esenli, F., Uz, V., Esenli, V., Külah, T. (2010). Ceramic properties of kaolinized tuffaceous rocks in Kesan region, Thrace, NW Turkey. Applied Clay Science, 48(3), 499–505.*

24. *Yun, K., Hirano, M., Yanase, S., & Ohya, Y. (2016). New Fabrication Method Suggestion of the Motor Core using Ceramic Precursor. International Journal of Metallurgical & Materials Science and Engineering (IJMMSE) ISSN (P), 2278–2516.*